Forest Research

Coast Forest Region
2100 Lableux Road, Nanaimo, BC, Canada, V9T 6E9, 250-751-7001

EN-020 Geomorphology March 2004

KEYWORDS:
Road deactivation, water management, landslides.

CITATION:
Dunkley, J.; Wise, M.P.; Leslie, M., and Collins, D. 2004. Effectiveness evaluation of road deactivation techniques on the west coast of Vancouver Island. Research Section, Coast Forest Region, BCMOF, Nanaimo, BC. Extension Note EN-020.

Effectiveness evaluation of road deactivation techniques on the west coast of Vancouver Island

by Jim Dunkley, Mike Wise, Mike Leslie, and Denis Collins

ABSTRACT

Long-term forest development on the west coast of Vancouver Island has resulted in extensive networks of forest roads, mostly constructed using cut and fill techniques. To reduce the environmental impact of landslides initiating from these roads, the forest industry since the late 1980s has been permanently deactivating roads after harvest in order to prevent further landslides. Over time, road deactivation objectives and methods have evolved. This study investigated the effectiveness of various deactivation methods, using a combination of satellite imagery, low-level helicopter observation, and ground traverses to examine a cross-section of deactivation sites in the Clayoquot Sound region of western Vancouver Island.

The study found that, while landslides initiating from deactivated roads do occur, they occur primarily on roads that were deactivated to earlier, pre-1995 standards. Later, more aggressive operational techniques (particularly full roadfill retrieval using benching, and innovative water management methods) appear to have made significant improvements to the stability of deactivated roads. Although these higher deactivation standards are more expensive to implement initially, in general they are more effective in preventing landslides, and reduce the likelihood of having to revisit a previously deactivated road for costly and dangerous remedial work.

AKNOWLEDGEMENTS

Funding for this project was provided by the Province of British Columbia's Forest Investment Account. Bob Patrick, Senior Geotechnical Engineer for EBA Engineering Consulting Ltd., provided review comments. Karl Kliparchuk of McElhanney Consulting Services Ltd. provided technical support relating to the QuickBird satellite imagery.

CONTACTS

- Jim Dunkley, Regional Geoscientist, Coast Forest Region, 250-751-7352. jim.dunkley@gems6.gov.bc.ca
- Michael P Wise, GeoWise Engineering Ltd, North Vancouver, BC, 604-626-9308. wise1@telus.net
- Denis Collins, Research Manager, Coast Forest Region, 250-751-7121. denis.collins@gems4.gov.bc.ca
- Mike Leslie, Mike Leslie Consulting Ltd., Duncan, BC, 250-748-1331. mdeact@shaw.ca

BRITISH COLUMBIA

Coast Forest Region

INTRODUCTION

Forest development has been carried out on the west coast of Vancouver Island for over a century. Technical advancements in logging equipment, as well as the decreased supply of easily accessible timber in valley bottom areas, resulted in the need for more extensive road networks. For road construction, cut and fill (sidecast) was the primary technique used to construct roads on hillslopes prior to 1995. During sidecast construction, material was excavated from the upslope side of the road and "sidecast" onto the downslope side of the road. Only a portion of the road width was excavated into the slope; this feature was often termed the "bench". In some cases, right of way timber was not removed from

Figure 1. Roadfill failures due to sidecast road construction on steep slopes above Hesquiat Lake.

the low side prior to roadfill placement, and these felled trees were left to support the roadfill. Over time, this wood debris decayed and structural support decreased significantly. As a result, many of these roadfills slipped, initiating significant landslides.

Concerned over the environmental impact of these road-related landslides, the forest industry in the late 1980s began to deactivate logging roads with the intention of preventing further landslides. The deactivation of forest roads falls into two broad categories. The first is "deconstruction", which involves the retrieval of roadfill material and restoration of hillslope drainage paths. This type of deactivation, also known as "hillslope restoration", is particularly important on steep slopes where small landslides or alteration of hillslope drainage may cause larger landslides that affect downslope resources. The second type of deactivation is "preventative maintenance" to reduce significant disruptions in hillslope drainage. Preventative maintenance is commonly carried out on steeper slopes where road access continues to be required for the short term, or on more gentle slopes where potential landslides are not a concern.

There are many examples of sidecast construction and landslides in the Escalante River-Hesquiat Lake area on the west coast of Vancouver Island. An earlier review of road construction in the area indicated that the landslide rate increased from a natural rate of 0.18 ha/year prior to 1968 (pre-logging) to 4.7 ha/year by 1982. Most of this increase was attributed to road construction (Lewis and Liard 1985). Figure 1 shows sidecast construction and landslides on the lower, mid and upper-slope roads in the Hesquiat watershed. These roads were later deactivated in 1997.

PROJECT OBJECTIVES

Road deactivation has evolved over time as the objectives and methods have become more defined. The purpose of this study was to look at a cross-section of deactivation standards within a sample study area in order to determine whether employing higher deactivation standards results in greater stability of the roads and thus lower negative effects on resources.

Therefore, the emphasis of this study is to evaluate the performance of specific deactivation techniques, and,where a technique has not achieved its objectives, examine the site carefully to determine how improvements can be incorporated into future work to prevent landslides following deactivation.

The study area was chosen because it has steep slopes with areas of numerous road failures. A wide range of deactivation standards has been employed during deactivation of old forest roads in the study area, allowing for relatively easy comparisons. Specific sites were chosen for close inspection on the basis of their specific deactivation age or standard, the deactivation technique used, or their previously known high hazard or risk situation. These latter sites were designated "monitor sites" in the project database maintained by the South Island Forest District for its Watershed Restoration Program activities. Other sites were identified following review of high-resolution satellite imagery. Once sites were chosen, they were inspected using a combination of on-site ground truthing, low-altitude aerial review via helicopter, or satellite photography using digital imagery from DigitalGlobe's Quickbird satellite (see Kliparchuk and Collins 2003).

This study differs from routine effectiveness evaluations in that it covers a range of deactivation techniques. Effectiveness evaluation studies would normally test whether a specific method produced a desired outcome. This study looks at the results of road deactivation to differing standards. There have been no regularly timed reviews of the sites, nor were there any control sites.

STUDY DESIGN

The techniques used for road deactivation have changed over time. This study was designed to determine the effectiveness of

various deactivation techniques, using site observations and satellite imagery. Sites with different deactivation techniques were selected throughout the study area, and recent observations were made regarding the presence or absence of landslides (or indicators of potential landslides).

Some areas exhibited deactivation of differing standards within the same road system. In other cases, different standards and techniques are spread across different watersheds.

It is important to note that considerable time may have to pass to test the performance of deactivated roads. This is due to the time needed for the area to experience the relatively large storms which feature the rainfall intensity that commonly contributes to the occurrence of landslides. However, even with repeated large storms, it is difficult to accurately determine "effectiveness" due to the large variation in site factors along the road and the inability to measure the number of landslides that were prevented by road deactivation.

Effectiveness evaluations of road deactivation techniques typically involve intensive evaluations of specific sites or road sections. As shown in Figure 2, these evaluations fall between "routine evaluations" and "operational techniques refinement". For road deactivation, routine evaluations are commonly carried out shortly after the completion of road deactivation work, whereas operational techniques refinement projects consider the techniques that were used and how to improve them.

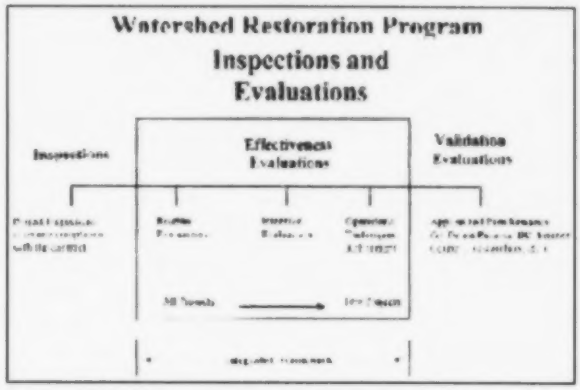

Figure 2. Effectiveness evaluation in watershed restoration (Gaboury and Wong 1999).

STUDY AREA DESCRIPTION

The study area is within the Clayoquot Sound region of western Vancouver Island. The area extends from Toquart Bay in the south to the Escalante watershed in the north (Figure 3).

The study area includes the westernmost peaks of the Vancouver Island Ranges and the slopes down to the Estevan Coastal Plain. The Island Ranges consist of pre-Cretaceous sedimentary and volcanic rocks that are cut by numerous granitic intrusives (Holland, 1976). In the study area, these mountains are commonly from 900 to 1000 m in elevation with occasional peaks reaching 1200 m. Glaciation has modified almost all of the peaks; all but the highest are relatively rounded. Additionally, deglaciation carried considerable sediment to the west side of Vancouver Island, creating relatively thick coastal plains and tills on hillslope areas.

Surficial deposits within the study area range from deep (>1 m) morainal deposits in the glaciated valleys to generally thinner morainal deposits on the mid to upper slopes. Variable colluvial deposits may overlie mostly continuous till veneers (<1 m) on the steep, upper slopes.

The study area lies within the temperate coastal rainforest that extends along the Pacific coast of North America from Alaska

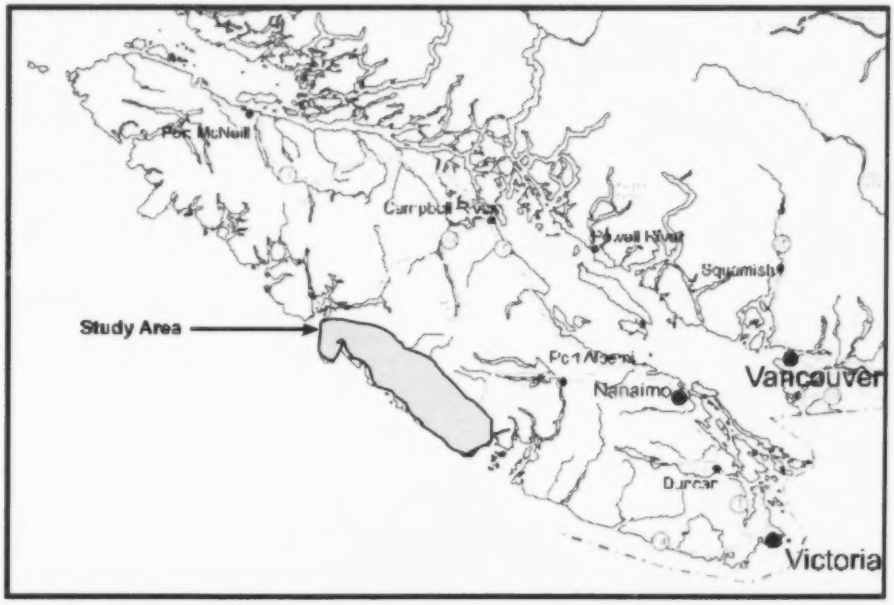

Figure 3. Location of study area.

to northern California. The area has wet, cool winters and moderate summers. Annual precipitation in the study area ranges from around 3,000mm in the northern watersheds (Chapman 1996) to over 4,600mm at the head of inlets at Clayoquot Sound. Up to 80 percent of all precipitation occurs in the months between October and March (Howes 1981). Coastal storm fronts roll over the coastal plain and rise sharply when confronted with the inland mountains. This orographic uplift causes intense rainfall activity, often very localized, which in turn can cause the initiation of debris avalanches and debris flows.

HISTORY OF ROAD DEACTIVATION

Road deactivation started in the late 1980s with the recognition that measures were needed to stabilize forest roads on steep slopes. Much of this early deactivation was limited to work at established streams or road segments where landslides were imminent or had recently occurred. Deactivation evolved with a greater understanding of techniques, particularly the importance of water management and roadfill pullback. This was spurred by government investment in the Watershed Restoration Program of Forest Renewal BC. In later years, the Forest Practices Code legislated deactivation (preventative maintenance or hillslope restoration) as part of the design life of a forest road.

Table 1 shows the evolution of deactivation techniques from 1987 to the present. In conjunction with the increasing emphasis due to regulations, techniques were developed to better manage water and retrieve roadfill during pullback activities. Note that water management and roadfill pullback are considered separately in the table. Water management is commonly carried out at specific sites along the road, whereas roadfill pullback is carried out for segments of the road.

During early deactivation work, techniques were used to manage the water along the road and prevent concentration at isolated locations or significant disruption of hillslope drainage. Limited pullback was carried out, and often only succeeded in partial roadfill pullback. Material was commonly piled in the centre of the road, leaving long exposed roadcuts and ditches intact. Even though this early deactivation was an improvement on the existing (often unstable) conditions, the roads were still able to divert water. At some locations, such as gully crossings, considerable roadfill remained that could be unstable. Note also that in early deactivation work, water management and roadfill pullback techniques were not effectively integrated. For example, open cross ditch sites were used in areas of roadfill pullback, limiting the amount of roadfill that could be placed on the stable bench.

Early deactivation work was not successful at preventing landslides in many locations. Wise et al (2001) documented the conditions in the Escalante Watershed during forest development and early deactivation. Following a seasonal storm in January 1996, in excess of 400 landslides were observed throughout Clayoquot Sound, many from areas of early deactivation.

Three years of deactivation in the Escalante area to a higher standard proved that the cost of fixing older, inadequate deacti-

Table 1. Evolution of road deactivation techniques.

	Road Deactivation Techniques for Hillslope Restoration	
Year	**Water Management**	**Roadfill Pullback[1,2]**
1987 to 1990	• Cross-ditches and waterbars, primarily located at culvert locations. • Few additional cross-ditches or waterbars for overland flow or seepage.	• Limited roadfill pullback carried out. • Material placed in middle of road. • Ditchlines intact behind pullback.
1991 to 1994	• Cross-ditches and waterbars located at culvert locations. • Additional cross-ditches and waterbars located at regular intervals (measured spacing along road). • Little attention placed on location or outfall consequence.	• No benching to retrieve roadfill. • Road surface and ditchline intact. • Roadfill placed against roadcut. • No sorting of debris prior to fill placement. • Large woody debris and road ballast placed under roadfill and within ditchline and against roadcut.
1995 to 1996	• Cross-ditches and waterbars located at culvert locations. • Regular interval spacing discouraged. • Attention paid to locating cross-ditches at flow and seepage sources.	• Benching common practice to retrieve roadfill. • Attention paid to road surface decompaction and subsurface o utsloping to initiate water flow. Ditchline intercepted. • Wood debris no longer buried. More sorting of roadfill material. Wood debris and organics randomly scattered on recontoured surface.
1996 to 2004	• Cross-ditches and waterbars located at culvert locations. • Regular interval spacing no longer occurring. Cross-drain structures located at source of flow. • Blanket drains, trench and French drains used to accommodate flow through areas of roadfill pullback.	• Benching common practice to retrieve roadfill. • Road surface removed and subsurface outsloping from ditch invert. • Wood debris no longer buried. More sorting of roadfill material. Wood debris and organics randomly scattered on recontoured surface.

Note: 1. Full pullback without benching inevitably left significant amounts of sidecast fill on the hillslope, resulting in potential instability
2. Full pullback with benching generally retrieved all (or most) sidecast roadfill.

vation was about five to ten times the cost of the original deactivation work. These higher costs stemmed from having to reactivate previously deactivated roads and then deactivate them a second time to a higher standard. This later deactivation work recognized the importance of restoring the hillslope profile to the pre-construction geometry. This included both sub-surface flow for water management and roadfill pullback to retrieve all the roadfill along the road, using end-haul if necessary at large gully or landing areas.

Since the later deactivation work required a greater level of effort, site-specific assessments were used to develop risk-based plans for deactivation. These risk-based plans involved assessing not only the conditions along the road, but also the stability conditions below the road as well as the presence or absence of elements at risk (fish habitat, highways, etc.). This later deactivation is typically more thorough and more expensive in recognition of the very high cost of returning to a site to carry out additional stabilization or remedial work.

Possibly one of the most important advances in deactivation was benching during roadfill pullback. This involves excavation into sidecast roadfill or into undisturbed ground near the outside of the road and using the lower platform to reach more roadfill. Benching proved beneficial for three reasons:

1. With excavation into undisturbed ground, the operator could visually determine the extent of natural ground, and position the excavator on stable materials;
2. The bench depth below the road grade allowed for greater reach and the pullback of additional roadfill; and
3. Removal of the outer portion of the road left an "outsloped" profile of natural material, reducing the likelihood that intact ditchlines under the pullback material would divert water across the slope for a significant distance.

However, it should be noted that a cost-benefit versus hazard reduction comparison may suggest that only limited benching be conducted, as the cost to continue benching may not produce the desired (or only limited) hazard or risk reduction.

Another important advance in road deactivation was the recognition of how important it is to make full use of the available room on the bench for the placement of roadfill pullback for hillslope restoration. The bulking of material during initial road deconstruction requires that the space along the bench be used efficiently for the placement of pullback materials. To use space more effectively, blanket drains and trench drains were utilized. These techniques allow for more roadfill material to be placed on the bench, meaning less material must be end-hauled for complete roadfill pullback, while continuing to provide for adequate water management.

Road deactivation has greatly reduced but not totally eliminated landslides caused by road failures. Previous studies have examined landslides from deactivated roads, in most cases to review work carried out and to evaluate specific techniques.

Rollerson et al (1999) found a number of common situations relating to landslide occurrence following deactivation. These included:

- marginally stable areas below cross-ditches;
- areas of partial pullback (or areas where complete roadfill pullback was not possible);
- partial pullback at gully crossings; and
- cutslopes where slides or slumps occurred.

The study concluded that various factors contributed to the slides in the study, but water management and fill retrieval were almost always involved, either separately or together. It was also important to note that some of these landslides were considerably larger than others, likely related to the stability of the slopes below the road.

Golder Associates Ltd. (2003) studied deactivated road sections on steep slopes within 10 watersheds on Vancouver Island (including some on the west coast) as well as road sections within three watersheds in the Fraser Valley. For the 113.7 kms of road on Vancouver Island and the 57.9 kms of road in the Fraser Valley, Golder found seven post-deactivation failures along the roads and six post-deactivation landslides that initiated some distance below the deactivated roads. Based on this study, landslides along post-deactivated roads occurred at a frequency of one landslide per 13.2 km of deactivated road (based on all 13 landslides observed).

SITE OBSERVATIONS AND INTERPRETATIONS

ROAD AND SITE CONDITIONS

Virtually all of the roads in the study were constructed using sidecast methods, primarily with bulldozers working with excavators. Organic material was generally not removed prior to sidecasting. The roads were constructed to the "standard of the day", which involved minimal, if any, end-haul of material to limit the roadfill volumes on steep slopes. Most roads did not have grade breaks to help maintain hillslope drainage paths or changes in alignment in small open slope depressions to limit the amount of roadfill in these small, locally steep areas or small stream channels. Figure 4 shows an example of road deactivation to restore drainage at a small stream during deactivation. Road construction had originally mostly filled in the small stream in order to maintain the grade.

At locations where the excavated material was allowed to slide down a steep slope during construction, the sidecast material formed a "sliverfill", often with a relatively thin depth (less than 1m) that may not overload the natural slopes underneath it. In many other cases, however, the sidecast material was supported by large woody debris or stumps which deteriorated over time, decreasing the stability of the roadfill and contributing to the occurrence of landslides. Figure 5 shows an example of roadfill pullback for deactivation and hillslope restoration.

As noted earlier, all sites were reviewed aerially via helicopter at low levels. Sites from the north end of the study area south to the north-facing slopes of Hesquiat Lake were also reviewed using high-resolution satellite imagery from the QuickBird satellite. In addition, ground traverses were carried out in the Lost Shoe / Thunderous watersheds along road KL655, between Sites 4 and 5, and near Kanim Lake along road K4 at Site 17.

Aerial reviews were made via low-level helicopter flights over

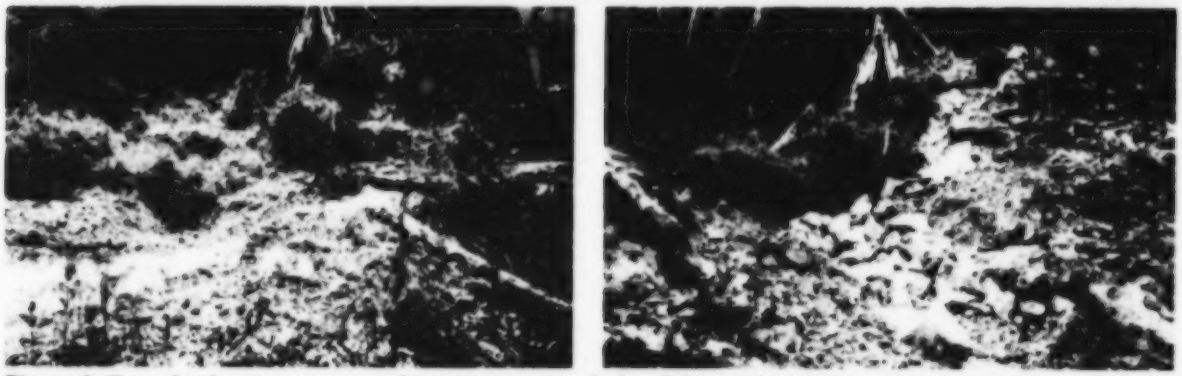

Figure 4. Example of water management for stream crossing – before (left) and after photos.

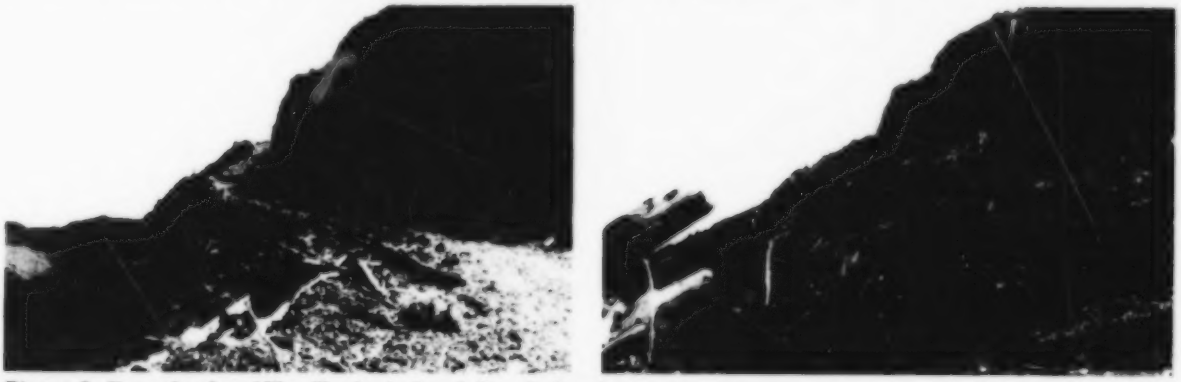

Figure 5. Example of roadfill pullback – before (left) and after photos.

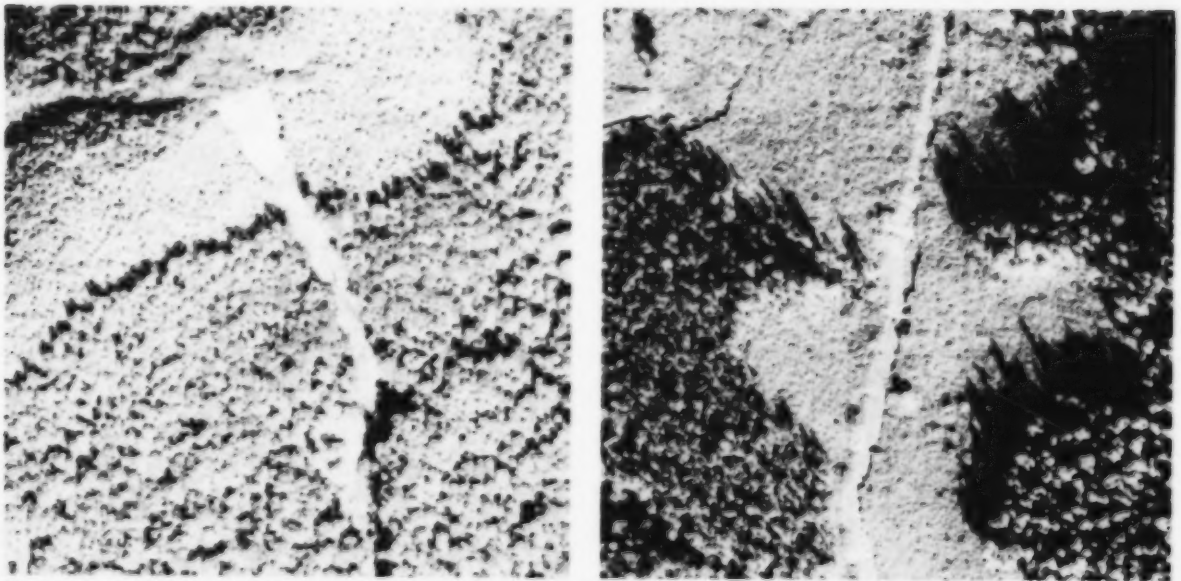

Figure 6. Quickbird satellite images: at left, a post-deactivation roadfill landslide; at right, cross-ditching along a deactivated road.

sites, looking for signs of instability or significant anomalies. All sites reviewed via helicopeter showed conclusive evidence regarding how the deactivation technique was functioning. See Table 2 for a summary of deactivation features by site.

Post-deactivation landslides, such as those in the Hesquiat Lake area, are clearly visible in the QuickBird satellite imagery (Figure 6). Other sites with increased displacement or loss of material from headscarps are also discernible on the change detection imagery.

Areas with trench and blanket drains in the Hesquiat and Escalante watersheds, reveal no new landslides, but the imagery is not conclusive regarding other, more subtle, signs of instability (Figure 7). Helicopter reviews were needed to confirm the stability of the sites in these areas.

The Lost Shoe/Thunderous watersheds (Figure 8) offer an excellent study area for comparing deactivation standards due to the significant variation in techniques used on roads on similar slopes. Sites 4 and 5 on Road KL655 include post-deactivation landslides following work carried out in 1994. The deactivation standards included pullback of sidecast material without benching in order to retrieve material which was out of the reach of the excavator as it sat on the road grade. As a result, crossditches were constructed with outlets on residual roadfill that was left following pullback activities. Aerial and ground observations identified two additional post-deactivation landslides between the two sites, with both these newer events initiating at the outlets of crossditches. At other crossditches along the road, signs of instability were noted, such as small slumps or tension cracks at crossditch outlets or along the lower edges of the pullback. Sites 6a and 6b include different deactivation techniques on upper-slope and mid-slope roads. Site 6a is along Road KL655

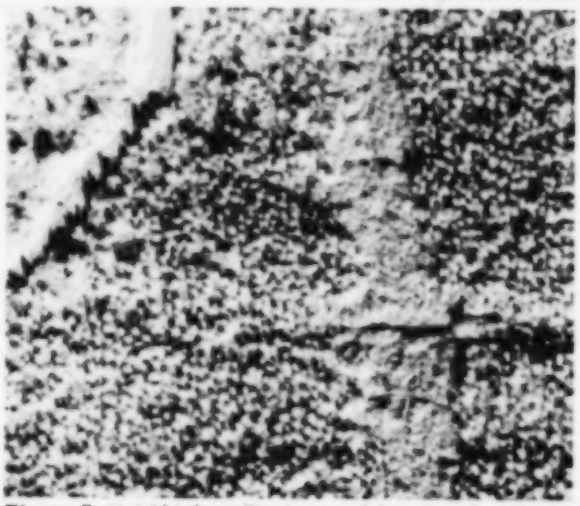

Figure 7. Quickbird satellite image of deactivated road with trench drains (right side of photo). Note revegetation vigour at wetter trench drain sites.

while Site 6b is on the mid- to-lower slope Road KL622, deactivated in 1995.

Deactivation along Road KL622 included full pullback requiring benching, full decompaction of the roadbed and outsloping of the subsurface. Site 8, on a spur of Road KL622, included trench drains for water management. There have been no post-deactivation failures along Road KL622 or its spurs.

Near Hesquiat Lake (Figure 9), Sites 22 and 23 are on Roads H402 and H402C, respectively. Deactivation work along these roads in the early 1990s included minor pullback of sidecast

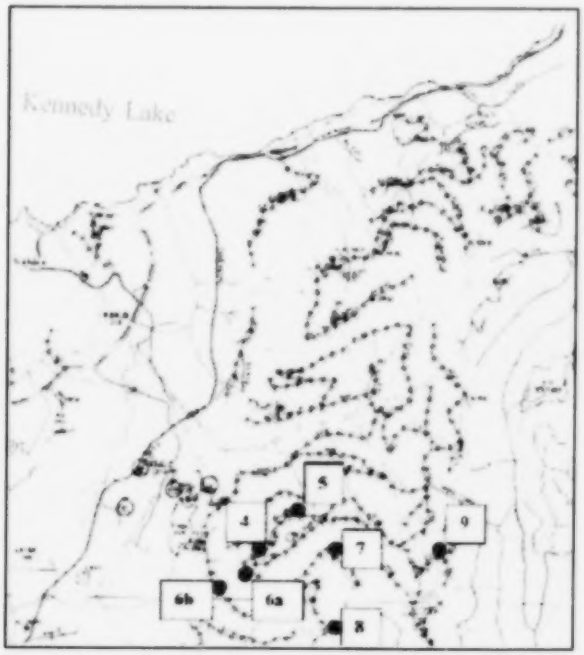

Figure 8. Site locations in Lost Shoe/Thunderous watersheds.

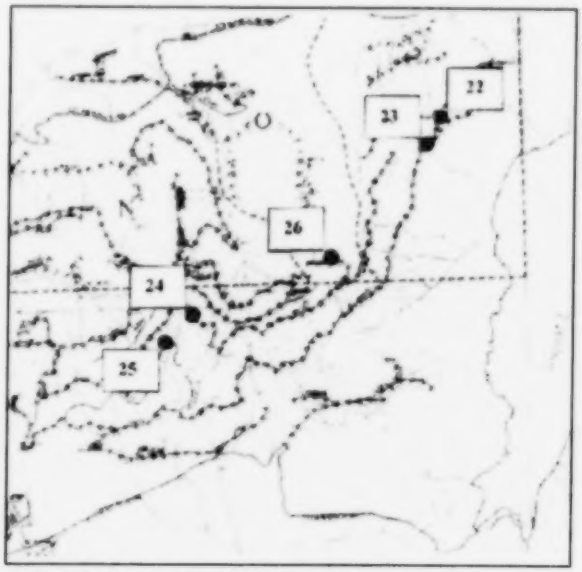

Figure 9. Site locations in Hesquiat Lake area

roadfill and water management using crossditches. These roads have four post-deactivation landslides. These landslides are clearly evident on the satellite imagery, and an aerial review found they will likely continue to be unstable without further intervention. It may be feasible to use explosives to relieve the amount of fill on these sites (see Muir et al 1999).

Sites 24 and 26, near Hesquiat Lake, are on upper-slope roads of similar age and terrain as Sites 22 and 23. These sites were deactivated in 1997-98 with later deactivation techniques that included full roadfill pullback (with benching) and water management using techniques such as blanket drains, trench drains, French drains as well as cross-ditches. No landslides have initiated from the roads deactivated with these later techniques, and no signs of instability were noted during the aerial inspection.

Other areas reviewed included eight sites in the Kanim Lake watershed and eight sites in the Escalante watershed. All of these sites are along roads deactivated in 1997-98 where full pullback, outsloping, and the most recent water management techniques were used. The Kanim Lake sites featured numerous trench and blanket drains. Ground observations at Site 17 and aerial observations of the other sites indicated no signs of instability.

In the Escalante watershed, six of the sites were "monitor sites" where minor slumping was previously noted immediately following deactivation, or full roadfill pullback could not be achieved due to safety concerns. Despite these concerns the sites appeared

Table 2. Site location and deactivation features

Site #	Watershed	Road	Deact year	Description (length, position, slope, feature)	Water mgnt technique	Pullback technique
4	Lostshoe/ Thunderous	KL655	1994	• 1,400m • upper slope • >65% lower sideslope • landslide, station 0+514	• Cross-ditches	• partial pullback • road intact • no benching
5	Lostshoe/ Thunderous	KL655	1994	• 1,400m • upper slope • >65% lower sideslope • landslide, station 0+942	• Cross-ditches	• full pullback • road intact • no benching
6a	Lostshoe/ Thunderous	KL655	1994	• 1,400m • upper slope • >65% lower sideslope • 4 post deactivation landslides, indications of instability	• Cross-ditches	• partial pullback • road intact • no benching
6b	Lostshoe/ Thunderous	KL622	1995	• 2,877m • mid-lower slope • >65% lower sideslope • intact, no indications of instability	• Cross-ditches	• full pullback • road surface decompacted and subsurface outsloped • benching undertaken
7	Lostshoe/ Thunderous	KL622	1995	• 2,877m • mid-lower slope • >65% lower sideslope • wildlife trees	• Cross-ditches	• full pullback • road surface decompacted and subsurface outsloped • benching undertaken
8	Lostshoe/ Thunderous	KL622A	1995	• 1,600m • mid-lower slope • 20-65% • French drain, station 1+075 – 1+118	• Cross-ditches • Trench drain	• full pullback • road surface decompacted and subsurface outsloped • benching undertaken
9	Lostshoe/ Thunderous	KL652	Fall 1994	• 1,020m • upper slope • 31-50% & >65% • wildlife trees	• Cross-ditches	• full pullback • road surface decompacted and subsurface outsloped • benching undertaken
22	Hesquiat Lake North	H402C	Pre 1994	• 925m • upper slope • >65% • landslide, station 0+825	• Cross-ditches	• N/A, no pullback undertaken
23	Hesquiat Lake North	H402 (1)	Pre 1994	• 7,343m • mid slope • 0-30% & >65% • landslide, station 1+490	• Cross-ditches	• intermittent pullback • road intact • no benching
24	Hesquiat Lake North	H400	1997/ 1998	• 4,880m • upper slope • >65% • French drain, station 4+050 – 4+075	• Cross-ditches • Blanket drains • Trench drains • French drains	• full pullback • road surface removed and subsurface outsloped • full benching to retrieve roadfill
25	Hesquiat Lake North	H403	Pre 1994	• 2,222m • mid slope • 0-30% & 51- >65% • gully debris jam, station 0+349	• Cross-ditches	• intermittent light pullback • road intact • no benching
26	Hesquiat Lake North	H407	1997	• 824m • upper slope • 51-65% • trench drains, 0+182 & 0+205	• Cross-ditches • Blanket drains • Trench drains	• full pullback • road surface removed and subsurface outsloped • full benching to retrieve roadfill

Note:
(1) H402, between Stations 3+775 and 4+200, was deactivated to a higher standard in 1998. Site #23 refers to the portion of H402 deactivated prior to this date.

stable, possibly due in part to the later deactivation techniques used along the adjacent road sections. The other two sites include water management techniques such as a series of trench drains and one large French drain. Aerial observations showed no signs of instability where these techniques were carried out.

Sites 7 and 9 in the Lost Shoe/Thunderous watersheds, and Sites 10 and 11 along Muriel Ridge above Tofino Inlet, were sites where wildlife trees were erected. Wildlife trees are groups of logs that are set upright in the ground to attract birds, typically cavity-dwellers and/or raptors. Wildlife trees were erected mostly in the mid-1990s and were dropped from deactivation prescriptions as standards evolved. Their discontinuation was due to concerns that wildlife trees may increase water concentration and saturation of soils due to flow down the hole excavated for the wildlife tree, and to logs decaying over time leaving holes deep in the fill. All four sites showed no signs of instability from aerial observation, with the exception of Site 11. At this location, the logs were placed on the edge of a gully and a portion of the gully sidewall slid after deactivation. One wildlife tree log entered the gully. Based on site observations, residual roadfill likely contributed to the landslide.

DISCUSSION OF RESULTS

Table 3 provides an overview of the study findings. Where there is incomplete roadfill pullback and no roadbed decompaction, leaving substantial volumes of residual fill (as seen at Sites 4 and 5, Figure 10) and likely an impermeable roadbed surface beneath the pullback, instability remains a problem. Road KL655, where Sites 4 and 5 are found, has open cross-ditches that outlet onto the residual fill. The result has been four landslides along the road, with further evidence of instability.

In the Lost Shoe/Thunderous watersheds, improved deactivation standards with more attention paid to fill retrieval and placement of the fill, as well as improved water management using trench drains in addition to cross-ditches, have resulted in higher apparent stability and no initiation of landslides since the deactivation. Figure 11 shows typical conditions along Road KL622 (Site 7) and KL652 (Site 9).

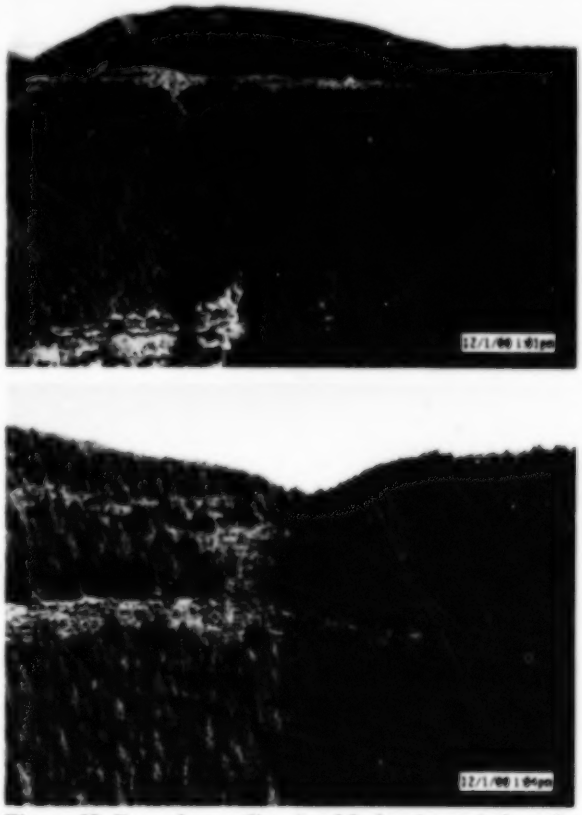

Figure 10. Example near Sites 4 and 5, showing typical conditions. Site 5 is on the extreme upper-left of the top photo; the post-deactivation landslide in the centre of the bottom photo initiates from the outlet of an open cross-ditch with only partial fill retrieval.

Table 3. Evaluation of deactivation techniques.

Sites	Technique		Landslides or Indications of Instability
	Water Management	Pullback	
4 & 5	• cross-ditches	• partial pullback • road intact • no benching	• 4 landslides have occurred since deactivation.
7, 8 & 9	• cross-ditches • trench drain	• full pullback • road surface decompacted and subsurface outsloped • benching undertaken	• No landslides have initiated since deactivation.
22, 23 & 25	• cross-ditches	• intermittent to no pullback • road intact • no benching	• 4 landslides have occurred since deactivation.
24 & 26	• cross-ditches • blanket drains • trench drains • French drains	• full pullback • road surface removed and subsurface outsloped • full benching to retrieve roadfill	• No landslides have initiated since deactivation.

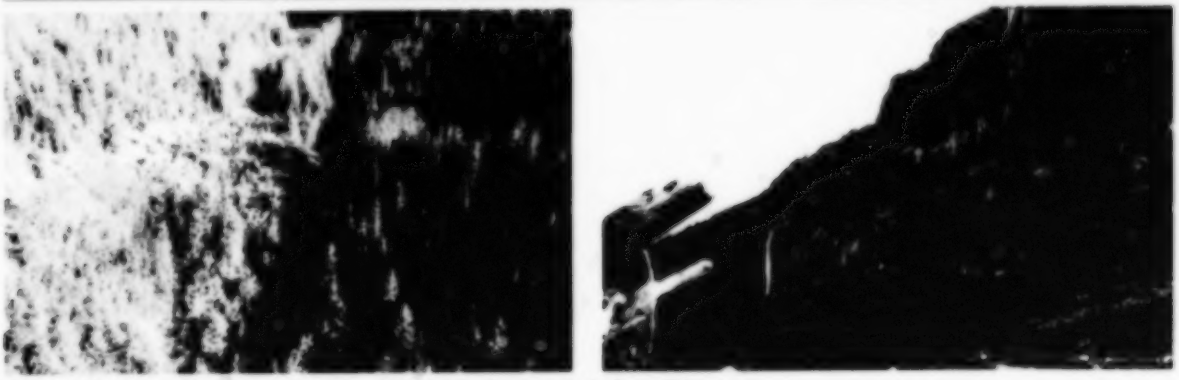

Figure 11. Example of Sites 7 (at left) and 9 (right), showing typical conditions.

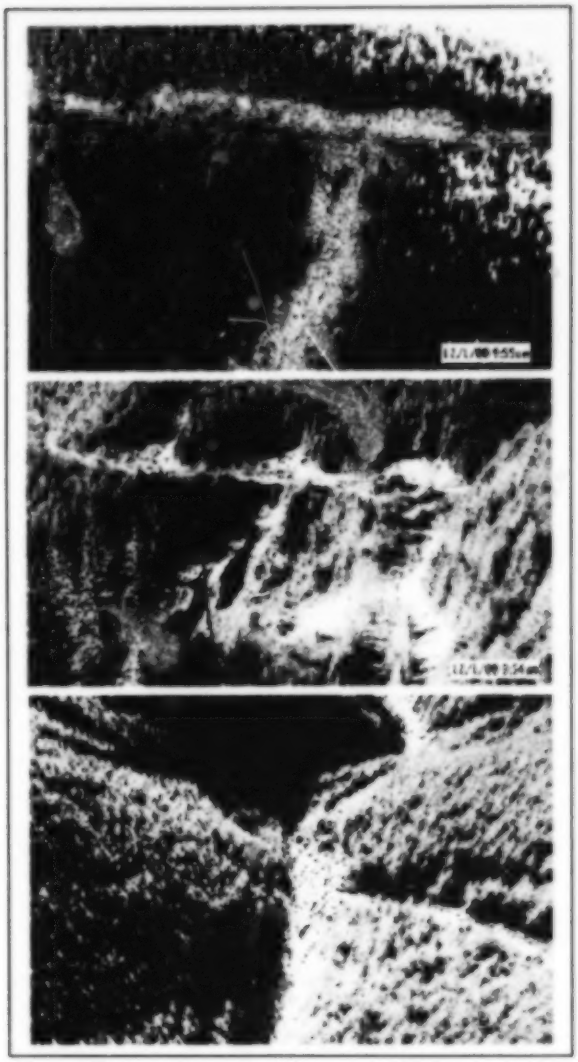

Figure 12. Sites 22 (at top), 23 (centre) and 25 (bottom), showing landslides attributable to earlier, lower deactivation standards.

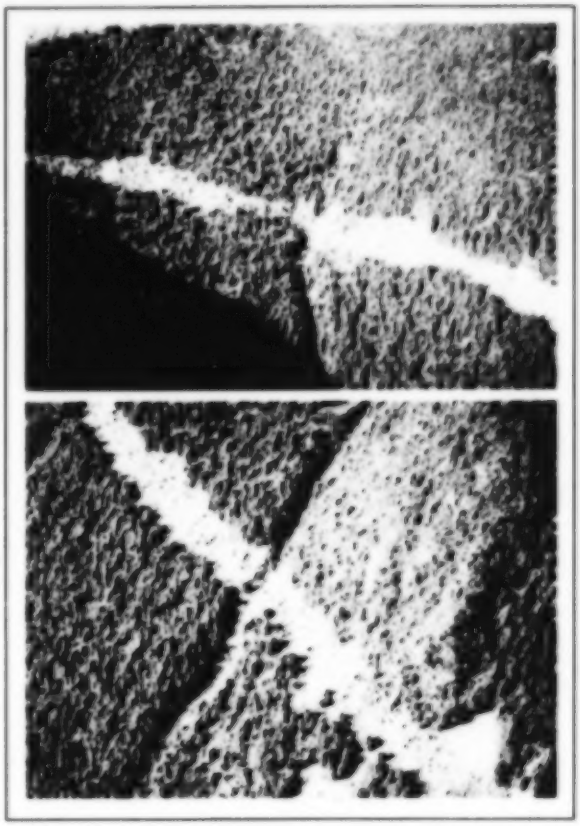

Figure 13. Example of Sites 24 (top photo) and 26 (bottom) in the Hesquiat Lake area, showing roads deactivated to later, higher standards. No landslides have initiated from these roads.

In the Hesquiat Lake area, earlier standards of deactivation, which included minor water management without adequate roadfill pullback, did not stabilize the roads. Figure 12 shows landslides initiating from Roads H402 and H402C which can be attributed to low deactivation standards. Full pullback of roadfill on these roads would have significantly increased the stability of these sites with a resultant lower likelihood of these failures occurring.

Later deactivation to higher standards within the same road network near Hesquiat Lake included full pullback including benching to retrieve roadfill, as well as blanket and trench drains in addition to cross-ditches to improve water management. Figure 13 shows fully deactivated upper-slope roads with trench drains in the centre of the two photos. No landslides have initiated from these roads since completion of the deactivation.

CONCLUSIONS

Standards for permanent road deactivation improved over the decade of the 1990s. Improved standards for sidecast fill pullback, as well as innovative approaches to transporting water across or along road sections, appear to have made improvements in the stability of deactivated roads. While landslides initiating from permanently deactivated roads do occur, this study on the west coast of Vancouver Island has shown that they have occurred primarily on roads that were deactivated to earlier standards. Later, more aggressive and innovative operational techniques appear to be functioning well.

Full roadfill retrieval using benching removes the most unstable feature of the old roads. Improved water management techniques, including trench, blanket and French drains, combined with roadfill retrieval, helps prevent saturation of potentially unstable material. In addition, these water management techniques help to solve the problem of where to place excess fill. Open cross-ditches take up valuable space when placing retrieved fill; by separating coarse rock and placing it in the trench, blanket and French drains, more available space is utilized for placement of retrieved material. Along with full roadfill retrieval, full decompaction of the roadbed occurs. This decompaction may be beneficial in reducing road-related landslides.

A major storm event has not caused widespread landslides within the study area for a number of years. In January 1996, a single storm caused approximately 400 landslides throughout the study area and north into Nootka Sound (Wise et al 2001). Numerous post-deactivation landslides initiated during the 1996 storm event, affecting many roads deactivated to earlier standards. While current standards cannot be shown to withstand such an event without a similar storm occurring, it should be noted that the Lostshoe/Thunderous Creek and Hesquiat Lake post-deactivation landslides are all recent events within the last two or three years, including at least two cases during the last year, while no landslides have occurred within the study area on roads deactivated to higher standards.

This study was conducted to determine the effectiveness of various road deactivation levels by using direct site observations to evaluate their performance. Returning in order to properly deactivate a road once roadfill pullback has been completed is extremely dangerous and expensive. It is therefore important to determine which deactivation techniques are more effective in reducing landslide events. Higher deactivation standards, although more expensive to implement, in general yield greater stability on steep slopes than lesser standards.

REFERENCES

Chapman, A. 1996. Analysis of precipitation for the west coast of Vancouver Island, in relation to the January 1996 landslides. Internal report for the Vancouver Forest Region, Nanaimo, BC.

Gaboury, M. and Wong, R. 1999. A framework for conducting effectiveness evaluations of watershed restoration projects. Watershed Restoration Technical Circular No. 12. Ministry of Environment, Lands and Parks and Ministry of Forests, Victoria, BC.

Golder Associates Ltd. 2003. Report on post-deactivation landslides: a review of the effectiveness of permanent road deactivation in selected watersheds. Unpublished report prepared for the Vancouver Forest Region, Ministry of Forests.

Holland, S. S. 1976. Landforms of British Columbia, a physiographic outline. Bulletin 48 BC Department of Mines and Petroleum Resources. Victoria, BC.

Howes, D. E. 1981. Terrain inventory and geological hazards: Northern Vancouver Island. APD Bulletin 5, British Columbia Ministry of Environment, Victoria, BC.

Kliparchuk, K, and Collins, D. 2003. Using QuickBird sub-metre satellite imagery for implementation monitoring and effectiveness evaluation in forestry. Research Section, Vancouver Forest Region, BC Ministry of Forests, Nanaimo. Technical Report TR-026, Tools and Applications.

Lewis, T. and Liard, R. 1983. Harvest planning in landslide prone terrain. Internal report prepared for Pacific Forest Products Ltd. and BC Ministry of Forests.

Muir, C. W, Wise, M. P., Erickson, D., and Collins, D. 1999. Stabilization of unstable roadfill using explosives: a case study from McNaughton Creek, British Columbia. *In* proceedings, IUFRO International Mountain Logging and 10th Pacific Skyline Symposium, Corvallis, Oregon.

Rollerson, T., Wise, Collins, D., M Wong, R.,Muir, W., and. Millard, T. 1999. Landslides and road deactivation. Presentation for the Vancouver Forest Region.

Wise, M., Leslie, M., Horel, G., Collins, D. and Warttig, W. 2001. Road deactivation for hillslope restoration: lessons learned on the Escalante Watershed Restoration Project. *In* proceedings, Land Reclamation Geotechnique, Vancouver Geotechnical Society Symposium, May 2001.